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AN EXPLORATIVE PHILOSOPHICAL STUDY OF ENVISAGING THE ELECTRICAL ENERGY INFRASTRUCTURE OF THE FUTURE

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Abstract

The electrical energy infrastructure is one of the key life-sustaining technologies of contemporary western society. This infrastructure is extremely complex due to its size, its multifarious technologies, and its interweaving with societal structures. Smart grids are important in future infrastructure, yet extant literature does not adequately address this complexity. This paper argues that different elements of the philosophy of Dooyeweerd offer a key to understand this intricate complexity more fundamentally. Key concepts are the ideas of normative practices, enkapsis (intertwinement) of practices, individuality structures, and ideals and basic beliefs. By developing these ideas in the context of smart grid engineering, our research contributes to philosophy of technology, philosophy of design, and philosophy of sustainability. It offers an ontological analysis of these infrastructures, pointing a direction to develop workable infrastructures, supporting the transition to a sustainable society.

Keywords

philosophy of technology, normative practice approach, electrical infrastructure of the future, smart grids, complexity, enkapsis, ideals and basic beliefs, sustainability

1. Introduction

The secure and reliable supply of sustainable energy is one of the greatest challenges of our modern society. Electricity is a very useful form of energy that has the advantage that it can be transported and distributed along and over long distances. Yet, even though global electrical energy consumption was 20.148 TWh in 2012, this was only 13% of global energy consumption (158.000 TWh), which includes considerable amounts of fossil fuels (EIA, 2013).[1] This means that if humanity is to

[1] TWh = Tera Watt hours = 10^{12} Watt hours.

plan responsibly for a sustainable energy use, as we committed ourselves in the 2015 Paris Accord, then the proportion that is electrical energy must grow faster than the current rates. This presents us with colossal challenges.

These challenges are heightened by the complexity of the infrastructure and the pace of technological development. The traditional fossil energy sources are becoming scarce. The concerns with the environment and warming up of the earth are also more perceptible. The nuclear energy alternative remains disputed due to safety reasons and the problem of radioactive waste management. Therefore, governments, universities and industries are cooperating intensively to develop sustainable / renewable energy sources that meet future needs and operational requirements. These include hydro, biomass, wind and solar energy. One of the drawbacks is that most of these sources are seasonal and / or intermittent.

It is widely recognized that the development and integration of sustainable sources also requires innovation of the electrical infrastructure and associated technologies for generation, transmission, distribution and storage of energy (IEEE 2014; EC 2017). The present electrical system is centred around large-scale electricity generators based on fossil fuels and hydro plants whereas the future electrical system will be based on a combination of a large-scale and small-scale distributed electricity generators based on solar panels and wind turbines. The changes in renewable energy generation will induce major alterations in the management and distribution of electrical energy. The present electrical system has to be made smarter in order to accommodate and balance demand and supply on local, regional, national, and transnational level. The electrical infrastructure of the future will be much more complex, not just extremely large, but also consisting of a great number of interoperable 'micro grids' or 'systems' . This has to be controlled in order to cope with the intermittent nature of sustainable sources and unpredictability of demand, and in response to market signals with different energy rates during the day. Furthermore, these complexities are exacerbated by non-technical issues, of personal, social and political nature.

The electrical energy infrastructure of the future raises a number of philosophical questions. For example, How to analyse the nature of complexity of this system? How to understand the structural nature of the infrastructure, with its plethora of parts and their relations? What constitutes context and on what basis the development of the whole infrastructure should be guided? How to prevent misuse of power? How to understand the influence on society? And, what should be the role of environmental values? It is also important to recognize the need to intimately know the current operation of the grid, as we 'cannot study the future' but only speculate about its evolution.

In this paper, we discuss how Reformational Philosophy might address four challenges related to this complexity:

- How to approach the complexity of the electrical energy infrastructure in a non-reductionist way?
- How to characterise the nature of this infrastructure including its dynamics and evolution?

- How to understand context of this infrastructure and how all its stakeholders should be taken into account?
- How to guide the development of this infrastructure in view of its size, interoperability and complexity?

This article has the following set-up. In Section 2 the complexity of the smart grids is briefly surveyed. In Section 3 the normative practice approach is proposed as a fruitful approach to understand smart grids in a less reductionist way. In Sections 4, 5, and 6 the structure, context and direction of smart grids are analysed. In Section 7 conclusions are drawn.

2. The Complexity of the Electrical Energy Infrastructures of the Future

There are several reasons that the complexity of the electrical energy infrastructure of the future is a challenge.

Most of the sustainable energy sources such as wind and solar have an intermittent nature. Controlled by the weather or natural cycles, the generation needs to be compensated by slack generators and energy storage devices to match the demand for energy. Thus, as we depend less on thermal power stations, it may be necessary to have forms of energy storage and to control the loads (Sandia 2013). Currently, the amount of electrical energy storage devices in the electrical infrastructure is limited, but it is likely soon to increase. Batteries in electric cars are also expected to play a part in this smoothing of the variations of renewable generation.

Presently, balance is maintained mainly by automatic control of central power plants that consume coal, oil or gas according to the need. As intermittent sources become more prominent in the electrical energy portfolio matrix, and as storage systems become significant, control and demand-matching systems grow in complexity.

The last few years has seen steady growth in distributed renewable generation, in which individual wind turbines and solar sources such as on farms and individual households have become popular. In the near future it is also expected that storage systems will be distributed, such as to capitalize on the capacity of electric car batteries. Furthermore, control demand, such as systems to switch off non-critical loads when demand is high and vice-versa when the demand / rates are low are being implemented. The increasingly distributed nature of electricity control presents even more challenges for the control systems. The IEC Smart Grid Standardization Roadmap (IEC 2010) provides a bird-eye view of the different norms and standards being developed to cope with the development of the grid of the future.

Within this context the concept of *smart grids* has surfaced, which embraces whole systems of local and central energy generation, storage, transmission and distribution, enabling intelligent control and information systems. Smart grids will be integrating micro grids (local systems) and super grids (high voltage transmission and bulk generation systems). Some significant technological developments are taking place, and it is believed that intelligent systems will be used to more comprehensively communicate, control, protect and balance supply and demand of energy. These include smart meters in households, industries and throughout the electrical grid. An illustration of the new concept of smart grids and the functional relationship among the different subsystems and technologies is given in figure 1. In this paper 'smart grid' and 'electrical energy infrastructure of the future' will be used interchangeably.

<< insert figure 1 >>

Smart grids face other challenges also. They must be able to cope with contingencies, disruptions and failures. Often the failure of one component of the grid 'cascades' to cause failure of other components, and this may result in large power blackouts. Data collection presents many challenges, e.g. lack of computational resources to analyse the data generated by a myriad of monitors and sensors, lack of integration and interoperability, difficulties with the setting of business models, lack of consumer involvement, need for better data protection and security, and the need for a legislative framework to ensure proper division of responsibilities (EC 2011).

So far, only technical complexities have been mentioned. Non-technical issues add extra layers of complexity. These range from biological issues, such as mould or vermin, through psychological issues to political and societal issues. The shape of the power industry has an enormous effect, with monopolistic corporations engaged in commercial and reputational competition, along with small firms for which survival is an issue, some of which are also seeking an ethical approach. Charging mechanisms determine much of how the grid must operate, and these can be changed at the whim of government or corporations. Governments can drive development but can also foster public distrust (Mah et al. 2012). The expectations and aspirations of the general population and of industries for seamlessly-abundant electric power is a major factor in planning of the electrical energy infrastructures. This means that the successful integration of renewable energy sources and implementation of smart grid technologies will require a holistic analysis and design process.

What will be the architecture of the future electric grid? Despite all know-how, the best answer to this question: *nobody knows*. The most probable and adequate answer to this question will be: the architecture of the electrical system of the future will not be designed at once but will evolve over many years from today's infrastructure through the deployment and integration of intelligent systems, through the development and implementation of new devices and components, and through political decisions and activities of citizens.

3. Understanding the Electrical Energy Infrastructure of the Future

To further understand smart grids requires not just a cataloguing of issues, as in the above section, but a theoretical framework that is broad enough to recognise all such issues, and make space for issues that might become apparent in future.

3.1. Present Approaches and Models

Complexity theory of various kinds has been applied to understanding smart grids. One strand is the complex network approach (Chu & Iu 2017), which treats the smart grid as a set of connected entities. This approach addresses topological and statistical characteristics, critical parts of the system, self-organising properties, and the idea of pinning the network onto a 'leading' agent. The agent-based approach (Nwana 1996) treats a smart grid as a set of interacting agents, in which agents are reduced to interactions. The multi-agent systems approach (Dave et al. 2011) tries to take a socio-technical approach, which acknowledges social as well as technical properties. It claims to be able to help us understand emergent behaviours. All these approaches exhibit a rather reductionist approach, as they treat smart grids as entities with topological or behavioural properties of generalised types.

The socio-technical approach (e.g. Mah et al. 2012) has the potential to be less reductionist, but tends to focus on abstract issues like governance, markets and innovation and tries to cope with complexity by separation into distinct levels, the relationships between which are poorly understood. The model of the Technical University of Eindhoven (TUE 2012) identifies three levels of complexity: technology (first level), business platforms (second level), and society and politics (third level). This model pays more attention to relationships between levels as well as within levels, but these relationships are still somewhat thin. A richer model has been suggested by the Working Group of the European Commission that spans three dimensions: domains, zones and interoperability layers (CEN-CENELEC-ETSI 2012). The domains cover the complete energy conversion chain from the energy generation to the end users. The zones represent the hierarchical levels of the power system management. The interoperability layers highlight the interoperability between components and systems. Also in this model the relationships between the different dimensions are indicated by lines and dotted lines.

However, all these theories and models have limitations. They do not reflect on the question 'What is the nature of a smart grid?' They also do not specify the relationships between the different dimensions and levels in a more ontological way. Most authors suggest that the development of smart grids can be controlled by engineers, though socio-technical approaches might go beyond this to include governments and corporations. A serious lack of almost all the models and approaches is that they tend to be descriptive or predictive, with little attempt to recognise normativity, so they have no basis to reflect critically on the direction in which smart grids are being taken.

3.2. Normative Practice Approach

The normative practice approach might open the way to more richly understanding smart grids. Originally, the normative practice approach was developed for healthcare (Jochemsen & Glas 1997). Later on, Jochemsen 2006) gave a more general description of the practice approach with many examples from health care and other practices. This approach was elaborated for other disciplines, e.g. agriculture

(Jochemsen 2012), technology (Verkerk 2014; Verkerk et al. 2016), the military (Burken & de Vries 2012), management and organisation (Verkerk 2015), and policing (Drenth 2016). The normative practice approach offers three perspectives to understand practices: structure, context and direction, see figure 2. The structure is related to the way in which a social practice as an individuality structure functions in different aspects or modalities of meaning, among which the aspect which 'qualifies' the nature of the primary process within that practice. The context addresses the influence of the natural, historical and cultural environment wherein a practice is developing itself. The direction concerns the ideals and basic beliefs that underlie a social practice. These three perspectives are not 'sold separately' but 'form' an integral part of a specific practice, so they must always be considered together.

<< insert figure 2 >>

A practice can be described as an individuality structure in which people act (Nicolini 2012; Verkerk et al. 2016). An individuality structure 'refers to the ways in which a thing is meaningful in the various aspects and it is what enables it to be that particular individual despite changes' (Basden 2008, 85). These aspects or dimensions are modes of being and modalities of meaning (Dooyeweerd 1955, I, 4). Every individuality structure exhibits a diversity of aspects, which are different from and irreducible to each other, and yet these different aspects form a 'coherence of meaning'. All that exists can be seen as 'things' of very different natures, such as material things (a stone), immaterial things (an idea), processes (the burning of wood), linkages (a marriage) or social practices (a social club). The nature of a thing is defined by its qualifying aspect. This approach offers a way to understand things as multidimensional or multileveled (Basden 2008).

We will argue that the normative practice approach has the potential to provide a better understanding of smart grids than the aforementioned approaches and models. Additionally, we will contend that the practice approach needs modification to understand the nature of smart grids and the relationships between different dimensions and levels. Finally, we will show that the 'normative content' of human practices is revealed by exploring the structure, context and direction.

3.3. Normative Practice Approach and Smart Grids

A first suggestion is that the normative practice approach would see smart grids not as a large collection of technical artefacts or a technical system, but as a human practice. Consequently, we must not consider only its structure, as many of the aforementioned approaches and models do, but also its context and direction. The inclusion of direction allows critical questioning of the direction in which smart grids are being developed, but not divorced from the 'realities' of structure and context. This contrasts with socio-critical approaches, which offer direction and criticality, but displays a negative tendency to criticise without suggesting solutions, to demolish without rebuilding (Brooke 2002). It also tends to narrowly focus on power and emancipation to define direction. The inclusion of context makes understanding more sensitive to not only the requirements of stakeholders, but also the vagaries of climate, public opinion and politics, but at the same time provides a basis to systematically think about those. This contrasts with chaos theory, which, while providing a way to think about vagaries, ends up thinking about little else.

Therefore, the first suggestion is that we might try to understand smart grids as being governed by multi-aspectual structures of individuality, context and direction, as a way to understand their complexity. Certainly, this would enable us to understand such things as network connectivity (kinematic aspect), control systems (formative aspect), physical and political contexts (physical and juridical aspect), and the variety of directions in which their development is pulled (social, economic, moral, etc.).

However, smart grids cannot be qualified so simplistically. Smart grids are collections of practices of very different kinds, and this collection is dynamically growing and changing in unpredictable ways. If we suggest a kinematic or formative qualifying aspect, then we downplay the important political, economic and social aspects, yet if we select one of those as the qualifying aspect, then we can lose sight of the physical aspect of climate change, which is the overall reason for moving towards smart grids. This reveals a fundamental flaw in most existing literature on smart grids, which views them from one of its aspects. None of these on its own provides the richness of understanding that is required: a smart grid must be understood as all of these practices working together in an interoperable way.

At least five different types of practices can be identified within the electrical energy infrastructure of the future[2]:

- Professional practices (engineering) that generate, transmit, distribute, and control electrical energy
- Professional practices (non-engineering) that produce energy
- Non-professional practices that produce energy
- Professional practices that use energy.
- Non-professional practices that use energy.

Professional practices (engineering) that produce, transmit, distribute, and control energy form the ‘spinal cord’ of the electrical infrastructure of the future. These practices are all formatively or technically qualified (Verkerk et al. 2016). They differ from each other by the nature of the technical process. Professional practices (non-engineering) that produce energy, e.g. an hospital or a department store whose roofs are covered with solar panels, have a moral and economic qualification, respectively. Such practices hold that the production of energy is not a part of its primary (qualifying) process but is (only) a part of its supporting processes. For non-professional practices that produce energy, e.g. households, the production of energy is not a part of their primary process. The qualification of these practice depend on their nature and character; for a household it is the social aspect.

[2] Verkerk et al. (2017) have shown that practices are embedded in organizations. Therefore, a philosophically more adequate formulation would be to say that smart grids are collections of differently qualified individuality structures in which practices are embedded. To prevent that the structural analysis in this article becomes too complex we have simplified the analysis by saying that smart grids are collections of practices.

Professional practices that use energy are quite differently qualified. Industry is economically qualified, health care institutions are morally qualified, courts are juridical qualified, and so on. Non-professional practices that use energy are also quite differently qualified. For example, households and sport clubs are socially qualified, a bible study group is pistically qualified, and an association of citizen that enjoy music is aesthetically qualified.

It has to be noted that the idea of a practice is more comprehensive than the idea of a set of technical artefacts or a technical system. A practice is a 'cooperative human activity' in which technical artefacts and technical systems are enkaptically interlaced. In other words, practices include human-artefact interactions (Schatzki 1996).

Our first conclusion is that the normative practices approach might help us to unfold a way towards understanding the complexity of the infrastructure of the future, but requires modification. A smart grid is not a 'thing' or a 'practice' with its own identity, but a 'heterogeneous' assortment of differently qualified practices that are 'tied together' by the phenomenon of 'electric energy generation-transport-distribution-consumption'. The next three sections discuss how the ideas of structure, context and direction need to be modified to facilitate the understanding of the nature and (normative) development of smart grids.

4. The Structure of the Electrical Energy Infrastructure of the Future

A smart grid can be seen as consisting of a plurality of social practices. In general, engineers tend to think in terms of sub-systems that are connected and work together. Thus, Dooyeweerd's theory of things and relationships is likely to be helpful.

4.1. Enkapsis

The first prospect is the 'part-whole' relationship, which is often relied on in systems thinking. But, for the infrastructure of the future, it is meaningless to suggest that the political or social practices are part of the network topology. Dooyeweerd allows us to understand the root of this meaninglessness: in a part-whole relationship the 'structural requirements of the whole entirely determine the functioning of the part' (Chaplin 2011, 133), such that whole and part are governed by the same qualifying aspect.

Dooyeweerd (1969, III), however, suggests a different kind of relationship among things and practices, that of enkapsis. An 'enkaptic structural whole' is a complete entity in which other entities are related that may be qualified by different aspects. Each such 'whole' might have its own structure of individuality, may also have a different direction and relate to the overall multi-aspectual context in different but interoperable ways. The enkaptic relationship allows an interlacement of wholes or practices with different identities, in which the 'encapsulating structure respects the independent functioning of the encapsulated structure that is determined by its structural principle' (Chaplin 2011, 133; Burken & De Vries 2012).

Dooyeweerd discussed five types of enkaptic interlacement:

- Foundational enkapsis, which occurs between meaningful wholes and the same thing viewed from a different aspect, such as the sculpture and the block of marble from which it is made;
- Subject-object enkapsis, exhibited by a hermit crab and its shell;
- Symbiotic enkapsis, exhibited by clover and its nitrogen-fixing bacteria;
- Territorial enkapsis, between, for example, a city and its university, orchestra or football team;
- Correlative enkapsis, between an *Umwelt* (environment, such as a forest) and its denizens (trees, fungi, etc.).

In enkapsis, one whole performs an enkaptic function within the other without being absorbed by it (for example the physical structure of the marble enables the expression of aesthetic representation) (Dooyeweerd, 1969, III, 124-125), in such a way that there is no 'resistance' or 'dualism' between the functions. Any resistance indicates flaw.

4.2. Smart Grids as Enkaptically Interleaved Practices

The idea of enkapsis might offer a way to understand smart grids and their encapsulated practices. It recognizes that a smart grid is a 'whole' that consists of different 'parts' (practices) which have an own qualification. The practices that generate, transport, and control energy are 'co-operable' with the structures that use energy. The idea of co-operability will be discussed in the next section.

Most of the above types of enkapsis are present within the electrical infrastructure of the future: foundational enkapsis can be found in the production and transport structures that are enkaptically interlaced in the control structures; correlative enkapsis in the grid with its generation plants, local generators like houses, transmission lines and distribution lines; territorial enkapsis in a wind farm and its geographic location; symbiotic enkapsis in the production and storage of energy; and subject-object enkapsis in the wind turbines and the agricultural land on which they are erected. However, that account covers only the technical side of smart grids and we may also detect types of enkapsis in the social and political sides: territorial enkapsis in a local authority and its geographical location (so that it is responsible for planning applications), correlative relationships between opinion formers and movements for or against renewable energy, and between individual decisions, organizational decisions and policy decisions, and between the desires, expectations aspirations of energy users and societal expectations (which might result in energy policy). However, some of these might be better considered part of the context rather than structure of the practice of smart grids, as discussed below.

The structure of the electrical infrastructure of the future *as infrastructure* cannot, however, be described solely by these types of enkapsis. For that reason we propose a new type of enkapsis: *network enkapsis*. The main characteristics of this enkapsis are: it is founded in human activities, it is shaped by individuals and organisational decisions, it has a specific infrastructural role in society, and it often incorporates other types of enkapsis. Moreover, it can described in terms of growth and decay (van Dijk 2006; Boutellier & Richardson 2013). In our opinion, world-wide networks like internet, internet of things, social media and so on are also characterised by 'network enkapsis'. Further research is required to investigate the idea of 'network enkapsis' in these different networks.

Our second conclusion is that the electrical energy infrastructure of the future is not a 'whole', in which structural qualities determine the functioning of the different practices in that whole, but a type of enkaptic interlacement of different practices with their own identity, and that it may be require a new kind of enkapsis – network enkapsis – that has yet to be fully discussed.

4.3 The Dynamics Within Smart Grids

In the foregoing section we have concluded that the electrical infrastructure of the future is not a 'whole' that determines the functioning of the 'parts' but there is an enkaptic interlacement of different kinds of practices. Our next question is how to understand the dynamics of the different practices within this enkaptic structure. At least three types of enkaptic interactions can be distinguished:

- Between practices that generate and that transport energy;
- Between practices that transport energy and control energy;
- Between practices that control energy and that use energy.

Chaplin (2011, 69) has introduced the idea of 'subservience', in which one whole is performing an enkaptic function within another whole. At first sight, the idea 'subservience' fits for example for the interaction between an intelligent energy control system and a hospital, in which the former has to focus on the energy requirements of the health care process. Then, 'subservience' can be described as the counterpart of disclosure: the moral function of the health care process discloses the meaning of the intelligent control system. However, at second sight the interaction is more complex. To guarantee a reliable energy delivery, the use of energy of the hospital has to be predictable and deviations have to be within certain limits. In order to do justice to the two-way character of the interaction between a user and the control system we prefer the word 'co-operable'. Comparable analysis for the interaction between practices that generate and that transport energy and practices that transport energy and control energy show that the idea of 'subservience' does not fit the interactions between these practices. Also for these practices the interactions are two-way so that the concept of 'co-operable' fits better. With this philosophic concept of co-operability we may understand the interoperability that characterizes electrical infrastructure.

On top of that, we have to realize that there is a network. In this network all practices interact with each other. This interaction cannot be described in terms like 'one whole performs an enkaptic function in another one' but has to be described in terms like 'every whole performs enkaptic functions in all other ones'. We would like to emphasize that the word 'co-operable' has to be understood philosophically. It describes the fundamental property of a network in which all practices interact with each other on an operational level: production, transport, control and use of energy (Verkerk et al 2016, 94-95).

Our third conclusion is that the dynamics between the different practices in the electrical infrastructure of the future can be described in terms of ‘co-operability’: practices interact with each other on an operational level.

5. The Context of the Electrical Energy Infrastructure of the Future

In the normative practice approach, the context is usually the social and cultural environment within which the practice operates. In section 3 we concluded that the infrastructure of the future is not a practice with its own identity, but a ‘heterogeneous’ assortment of differently qualified practices. Consequently, the idea of ‘context’ as the social and cultural environment can be used to understand the different practices of the smart grid but cannot directly applied to the smart grid as a whole.

The Triple I model as developed by Verkerk (2014), which is a variant of the normative practice approach, gives a clue to understand the complexity of the context of smart grids. The Triple I model, see figure 3, offers three perspectives to understand practices: the first ‘I’ refers to the ‘identity’ and ‘intrinsic values’ of a practice, the second ‘I’ to the ‘interests of stakeholders’ of a practice’, and the third ‘I’ to the ‘ideals and basic beliefs’ that are expressed by or are embedded in the practice. The second ‘I’ is based on the theory of stakeholders as developed by Freeman (2001) and the theory of individuality structures as developed by Dooyeweerd (1969, III).

<< insert figure 3 >>

Every practice has its own configuration of stakeholders. For example, there is a big difference in the stakeholder configuration of a classical nuclear plant, an onshore wind mill plant, and a local distribution network. The stakeholder configuration of classical nuclear plants is dominated by national and regional governments to guarantee a safe operation and prevention of ecological damage, large companies who deliver the nuclear technology, and action groups who critically follow the performance of the plant. The identity of all these stakeholders is different: it is governed respectively by their juridical, formative, and social aspect. The stakeholder configuration of an onshore wind mill plant is dominated by local authorities who have allocate areas and the local neighbourhood who welcome or resist such a plant. The identity of these stakeholders is governed by their juridical and social functions respectively. Finally, the stakeholder configuration of a local distribution network are the companies that generate energy, local industries, and households. The identity of these stakeholders is mainly governed by their economical function (the first two) and social function (the third) respectively.

Whereas the normative practice approach emphasises social context, for smart grids there are also physical and biotic contexts, constituted in the climate and weather patterns, and such things as pollution from fossil-fuel use and reduction of pollution from renewable sources. Unlike the social context, these aspects often cannot be controlled, though they might be predicted. Because Dooyeweerd brought pre-human, human-individual and social aspects together, this offers a foundation on which the context may be widened beyond those aspects discussed earlier.

Our fourth conclusion is that the context of an electrical energy infrastructure can be understood by analysing the stakeholder configurations of the different practices in the smart grid. Every practice has its own configuration of stakeholders, that consists out of differently qualified investors. In addition, the natural environment has to be taken into account.

6. The Direction of the Electrical Energy Infrastructure of the Future

To what extent is it possible, and desirable, to guide the development of a smart grid? The answer resides in the choice of the direction of this infrastructure. The direction of a system is the norm that guides its design, evaluation and development through time. In the case of the electrical infrastructure of the future, it is a question of 'How to develop an infrastructure that is characterized by network enkapsis?'.

The normative practice approach offers a clue to address this question: the perspective 'direction' highlights ideals and basic beliefs that shape practices. On the one hand, it recognizes that the existing practices are no 'neutral' structures but that they are co-shaped by prevailing ideals and basic beliefs. On the other hand, it shows that the development of new practices is guided by these ideals and basic beliefs (Jochemsen & Glas 1997, Jochemsen 2006, Verkerk et al. 2016).

We can see at least the following directional issues. Firstly, we have to recognise that the consensus among experts in this field is that 'nobody knows' what the electrical infrastructure of the future will look like. Consequently, there seems to be no common widely accepted vision that guides the development of this infrastructure. There are efforts to envisage architectures of reference for the development (CEN-CENELEC-ETSI 2012; NIST-USA 2013; Mengolini & Vasiljevska 2013). Secondly, the electrical infrastructure of the future will cover a large part of Western Europe. May be even countries in East-Europe and Northern Africa. In the worst case, every country will have its own policy and legislation with respect to these infrastructures. Thirdly, the decisions about the electrical infrastructure are not only made by producers and users of energy. In every country there are many stakeholders, e.g. regional and local authorities, banks, shareholders, and environmental action groups, that will exert power on the development of it. All these stakeholders may have their own policies and values. Fourthly, the technologies of the electrical infrastructure of the future are under development. The contours of some technologies can be sketched well whereas the contours of other technologies are still unknown. Finally, these considerations are more than practical concerns, they reflect the philosophical insight that the electrical infrastructure of the future is not a 'whole' which development is guided by its 'own' (internal) qualifying function, but that this infrastructure consists of a medley of practices which each is developed by its own qualification.

We return to our question: How to develop an infrastructure that is characterized by network enkapsis? In our view, the normative practice approach, especially in the Triple I variant, offers two ways to support a normative development of smart grids. The first way focuses on the intrinsic values of the engineering practices in the practices of the smart grid that generate, transmit, distribute, and control electrical energy. Increasingly, engineers are adopting ‘green values’ (Sioshansi 2012). It is the responsibility of engineers (and their bosses) to strengthen the position of green values in the development process of smart grids, because they cover a wider range of aspectual norms than previous approaches (Brandon & Lombardi 2005). This approach is an approach from ‘within’ the energy business.

The second approach focuses on the ideals and basic beliefs that are developed globally and crystallize in national agendas. These basic beliefs influence the attitudes, political agendas and behaviour of all citizens and all stakeholders. The national agenda contain many measures that support the development, implementation and roll out of the electrical energy infrastructure of the future. These measures will address the responsibilities of different stakeholders. For example, some countries have a relatively green policy so that the practices in that country are developed under guidance of a green directional component. Other countries put their primary faith in economic competition and so their energy sector must develop under the guidance of a profit motive. Ideals and basic beliefs are often hidden. Even in a supposedly green country there will be practices that are developed only under guidance of the profit motive, indicating something deeper than their stated responsibility for the planet or the future.

Our fifth conclusion is that there are two ways to support the normative development of the electrical infrastructure of the future, both of which can be informed by the philosophy underlying the normative practice approach. Firstly, by developing and applying green values that guide the engineering practices that generate, transmit, distribute, and control electrical energy. Secondly, by promoting the development of shared ideals and basic beliefs that influence the behaviour of citizens, corporations and institutions, and that support the development of more sustainable national agendas.

7. Conclusions

This paper addresses a philosophical understanding of the electrical energy infrastructure of the future (so-called smart grids). This structure is very complex, extremely large and involves many different and irreducible parties, sub-systems, technologies and post-technological factors.

The first research question of this study, discussed in section 3, is: How to address this complexity in a way that does it justice, in order to understand such infrastructure (smart grids) now and in the future? Our answer is that the normative practice approach, as developed by Christian philosophers, provides an escape from reductionist ways of thinking. It directs us to treat smart grids as practices rather than just sub-systems, and directs us to consider structure, context and direction. However, the normative practice approach needs to be modified in order to apply to such complex practices.

The second research question, discussed in Section 4, is how to understand the structure of the electrical energy infrastructure of the future. We have argued that such infrastructure is not a 'thing' with its own identity but is a heterogeneous mix of professional and non-professional practices. This can be understand via Dooyeweerd's notion of enkapsis, but we suggest that smart grids exhibit a new kind of enkaptic structure: network enkapsis. The interaction between practices in smart grids can be described in terms of 'co-operability': a two-way interaction on an operational level.

The third research question of this paper, discussed in Section 5, is: How to understand the context of within this infrastructure operates? To answer this question we have used the Triple I variant of the normative practice approach. We have shown that the context of an electrical energy infrastructure can be understood by analysing modal aspects and the stakeholder configurations of the different practices in the smart grid. Since each practice has its own configuration of differently qualified stakeholders, the context of the smart grid is very complex.

The fourth research question, discussed in Section 6, is: How to understand and guide the normative development of the electrical infrastructure of the future in view of its size and complexity? This question concerns direction and is very important to achieve a sustainable and coherent infrastructure, yet no individual party can drive the development of this infrastructure, because each practice in this infrastructure has its own direction. To obtain an 'orchestrated' direction two approaches are proposed,both of which are supported by the underlying philosophy. The first approach supports a change from within: by growing green intrinsic values that guide the engineering practices that generate, transmit, distribute, and control electrical energy. The second approach supports a change from outside: by promoting the development of shared ideals and basic beliefs that lead global, national and individual behaviours, attitudes and national agendas in more sustainable directions.

We would like to close this paper with four remarks. First, this paper has shown how Dooyeweerd's ideas, especially as expressed in the normative practice approach, show considerable promise in being able to address the extreme complexities facing the infrastructure of the future, more fully than extant approaches can. This helps fulfil Dooyeweerd's call that it is a 'matter of life for this young philosophy that Christian scholars in all fields of science seek to put it to work in their own speciality' (Dooyeweerd 1969, I, vii).

Second, our philosophical investigations have revealed a new type of enkaptic structure: network enkapsis. More research is required to characterize the nature of this enkaptic structure within the bounds of a stable interoperability of all functions and practices. In our opinion, this type of enkaptic structure is also present in other world-wide networks like internet, internet of things, social media and so on.

Third, the findings of our research are important for philosophy of design. It shows the importance of shared ideals and basic beliefs. Preferable not only on national level but even on a continental or global level. Further, it has to be investigated in more detail how ideals and basic beliefs will guide the design of this type of infrastructure.

Finally, this challenges Christians not to focus on their 'own' Christian ideals and basic beliefs but to contribute to the development of shared ideals and basic beliefs. C.S. Lewis (1979) reminds us that these types of ideas have to be based on normative practices: 'There is no sense in talking of "becoming better" (or "smarter") if better or smarter means simply "what we are becoming" – it is like congratulating oneself on reaching your destination and defining destination as "the place you have reached".' We need to strive towards unfolding normative professional practices within this complex enkaptic and interoperable reality of an electric grid infrastructure.

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Captions

Figure 1: Concept of the electrical energy infrastructure of the future that involves sustainable energy sources (source: https://www.smartgrid.gov/the_smart_grid/

Figure 2: Normative practice approach

Figure 3: Triple I model